Comment on “Comparison of strangeness production between A+A and p+p reactions from 2 to 160 A GeV”, by J. C. Dunlop and C. A. Ogilvie

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Abstract

A recent paper on energy dependence of strangeness production in A+A and p+p interactions written by Dunlop and Ogilvie [1] indicates that there is a significant misunderstanding about the concept of strangeness enhancement and its role as a signal of Quark Gluon Plasma creation. In this comment we will try to clarify some essential points.

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In a recent publication Dunlop and Ogilvie (DO) [1] studied the energy dependence of strangeness production and considered it from the point of view of a possible transition to Quark Gluon Plasma (QGP). In our opinion the DO paper does not reflect the status of the discussion on these subjects correctly and it is even misleading. We, therefore, feel the need to comment on the observation of anomalous energy dependence of strangeness production in nucleus–nucleus (A+A) collisions and its possible interpretation. In the first section of our comment we show that the data analysis part of the DO paper repeats our earlier work without, however, any reference to it. In the second section we argue that the DO proposal to search for the transition by studying the energy dependence of strangeness enhancement factor is unjustified and misleading.

I. Data on Strangeness Production

In 1994 the idea that the creation of a transient QGP state in the early stage of A+A collisions should be reflected in the collision energy dependence of basic observables triggered our analysis of results on hadron multiplicities in A+A and nucleon–nucleon (N+N) collisions. The work commenced from the relatively rich data on pion production [2]. In 1996 this study was extended to strangeness production [3]. The basic experimental observations concerning strangeness here called strangeness anomaly were the following:

- the strangeness to pion ratio in central A+A collisions increases rapidly with the collision energy up to the top AGS (15 A·GeV) energy; the ratio at top SPS (200 A·GeV) energy is approximately equal to the ratio at AGS;

- a very different energy dependence is observed for N+N interactions, a monotonic increase is seen at all energies, between top AGS and SPS energies the ratio increases by a factor of about 2.

This strangeness anomaly is rediscovered in the very recent DO paper [1] on the basis of data on central Pb+Pb collisions at SPS energy (158 A·GeV) [4] and Au+Au collisions at AGS energies [5]. After clarifying two points, the similarity becomes obvious:

1.) In the original paper [3] the strangeness to pion ratio was quantified by the measure

$$E_S \equiv \frac{\langle\Lambda\rangle + \langle K + \overline{K}\rangle}{\langle\pi\rangle} , \quad (1)$$

where $\langle\Lambda\rangle$, $\langle K + \overline{K}\rangle$ and $\langle\pi\rangle$ are mean multiplicities of Λ hyperons, $K + \overline{K}$ mesons and all pions, respectively. For the comparison of the A+A collisions to nucleon-nucleon interactions the N+N results were constructed by a proper averaging of p+p, n+p and n+n data. The above procedure yields the best experimental estimate of the total strangeness to pion ratio. Our compilations indicate that the K^+/π^+ ratio used in DO paper is closely (within 20–30 %) related to the E_S measure.

2.) In refs. [2,3] the energy dependence of pion and strangeness production is presented by using the Fermi energy measure:

$$F \equiv (\sqrt{s} - 2m)^{3/4}/\sqrt{s}^{1/4} \cong \sqrt{s}^{1/2} , \quad (2)$$

where $\sqrt{s}$ is the c.m. energy for a nucleon–nucleon pair and m is the nucleon mass. In the statistical model of the early stage of the collision both entropy and the early stage temperature are approximately proportional to F [8]. In the DO paper the dependence on $\sqrt{s}$ is studied.

Keeping these two technical differences in mind one observes that Figs. 1, 2, 3(5) and 4 in the DO paper are almost identical to, respectively, Figs. 3(4) in [3], 1 in [2], 7(8) in [3] (for the most recent version see also Fig. 3 in [6]) and Fig. 3 in [7]. Therefore, the analysis presented in the DO paper fully confirms the observations made in refs. [3,6,7] (however, without any references to these papers).

II. Interpretation of Strangeness Anomaly

The anomalous energy dependence of the strangeness to pion ratio in A+A collisions (see the previous section) was established experimentally and its connection with a possible observation of transition to QGP in A+A collisions between AGS and SPS was stressed in Refs. [3,8]. Note also that it serves as one of the basic arguments for the current study of the low energy (40 A·GeV) Pb+Pb collisions at CERN SPS [9]. In contrast to this suggestion it is proposed in the DO paper that in order to search for the transition to QGP

one should study the energy dependence of the strangeness enhancement factor, i.e. the increase of the strangeness to pion ratio between N+N and A+A collisions. The idea of strangeness enhancement as a QGP signal was formulated about 20 years ago [10] and was based on the estimate that the strangeness equilibration time in QGP is of the same order ($\approx$ 10 fm/c) as the expected life time of the fireball created in A+A collisions. Thus in the case of QGP formation the strangeness content is expected to approach its equilibrium value in QGP. This equilibrium value is significantly higher (factor 2 or more depending on energy) than the strangeness production in elementary N+N interactions. Furthermore it was estimated that the strangeness production in secondary hadronic interactions which may follow initial N+N interactions is small [11]. Therefore, if QGP is not formed, the strangeness yields would be expected to be much lower than those predicted by equilibrium QGP calculations[1]. For experimental and theoretical reasons it is convenient to analyse the strangeness to pion ratio in an actual study of strangeness production. Then a simple and elegant signature of QGP creation appeared: a transition to QGP should be signalled by an increase of the strangeness to pion ratio from the value close to that measured in N+N interactions at the corresponding energy to the level given by QGP in equilibrium. This idea motivated study of the strangeness to pion ratio in A+A collisions relatively to the corresponding ratio in N+N interactions as a function of nuclear mass number and collision energy.

The comparison of the above expectations with the data was for the first time possible in 1988 when the preliminary results from S and Si beams at SPS and AGS were presented. Experiment NA35 reported [12] that in central S+S collisions at 200 A·GeV the strangeness to pion ratio is two times higher than in N+N interactions at the same energy per nucleon.

[1]In the DO discussion of the results of the data analysis performed within hadron gas models the usage of the model parameters γ_S (strangeness saturation factor) and λ_S (strangeness suppression factor) have apparently been confused.

Surprisingly even larger enhancement (a factor of about 3) was measured by E802 in Si+A collisions at AGS [13]. Recent data on central Au+Au collisions at low AGS energies [5] complete the picture: strangeness enhancement is observed at all energies, it is even stronger at lower energies than at the SPS energy. Thus the interpretation in line with the original concept (strangeness enhancement → QGP) was put in question from the very beginning by the AGS data. At the low AGS energies one does not expect the creation of QGP and therefore one should not observe substantial strangeness enhancement. Consequently AGS measurements of strangeness enhancement larger than that at SPS clearly leads to the following conclusion: *the simple concept of strangeness enhancement as a signal of QGP is incorrect*. Furthermore the observed enhancement is very large (factor several), indicating that a potential connection between strangeness measured in A+A collisions and that produced in initial N+N interactions is lost. Therefore, the proposal of the DO paper to search for the transition to QGP by studying the energy dependence of the strangeness enhancement factor should be treated as unjustified and misleading, it is not based on any specific model or at least an intuitive physical picture.

From our point of view it is more natural to concentrate on the strangeness to pion ratio in A+A collisions instead of relating it to N+N interactions, which may only introduce additional problems into the data interpretation. This suggestion is justified by the statistical model of the early stage of A+A collisions [8] which, for a reasonable selection of the model parameters, predicts a transition to QGP between AGS and SPS energies and explains the observed strangeness anomaly by the presence of this transition. We would like to stress once more the simplicity of the argument, which relies on the basic assumption of the model that in both confined and deconfined matter a maximum entropy state is created at the early stage of the collisions. In confined matter the mass of strange and non–strange degrees of freedom are expected to be of the order of kaon and pion masses ($m_S \cong 0.5$ GeV, $m_{NS} \cong 0.14$ GeV), respectively, and the temperature is $T < T_C \cong 0.170$ GeV. Thus, strange degrees of freedom are heavy ($m_S > T$) and non-strange light ($m_{NS} < T$). Therefore, in the statistical model one obtains approximately

$$\frac{\langle n_S \rangle}{\langle n_{NS} \rangle} \sim \frac{T^{3/2}\ \exp(-m_S/T)}{T^3}\ , \tag{3}$$

which is an increasing function of T for $T < T_C(< 2m_S/3)$. In QGP $m_S \cong 0.170$ GeV and $m_{NS} \cong 0.01$ GeV. Both strange and non-strange degrees of freedom are light ($m \leq T$), and therefore one gets approximately

$$\frac{\langle n_S \rangle}{\langle n_{NS} \rangle} \cong \text{const}(T)\ . \tag{4}$$

Consequently within the statistical model of the early stage we find a simple explanation for a fast increase of the strangeness to pion ratio at low energies (Eq. 3) and its rapid saturation at high energies (Eq. 4) provided that the threshold for QGP creation is crossed.

Two striking predictions follow from our approach.

1.) *Very similar strangeness to pion ratio is predicted for SPS, RHIC and LHC energies.* This follows from the observations that the model predicts the transition to QGP to occur below top SPS energy (and above top AGS energy) and that in QGP the ratio $\langle n_S \rangle / \langle n_{NS} \rangle$ is almost independent of temperature (collision energy).

2.) *A non–monotonic (or kinky) energy dependence of the strangeness to pion ratio is predicted in the vicinity of the transition region.* This is due to the fact that the model predicts the transition to occur at an energy where the strangeness to entropy (pion) ratio in the confined matter is higher (or equal) than in the QGP. Thus an initial fast increase of the ratio is expected to be followed by a decrease (or a saturation) to the level expected in an equilibrium QGP. The decrease starts at the onset of the transition region (≈ 30 A·GeV) and ends when the pure QGP phase is produced (≈ 60 A·GeV) [8].

In Fig. 1 the discussd above predictions of the statistical model of the early stage calculated for $T_C = 200$ MeV [8] are confronted with the experimental data on strangeness to pion ratio. In the case of $T_C = 170$ MeV the onset of transition takes place at the top AGS energy and the non–monotonic behaviour is substituted by a kink in the energy dependence. In general, one might try to extend the model calculations to N+N interactions; in this case, however, canonical, and at low energy even micro-canonical, calculations are needed.

Note that this introduces additional dependence on model assumptions and parameters and therefore also from the point of view of our model study of strangeness enhancement factor only confuses the interpretation of the data.

We hope to have shown that the idea to search for QGP by studying the strangeness enhancement factor, as proposed by DO, is unjustified and may lead to misleading conclusions.

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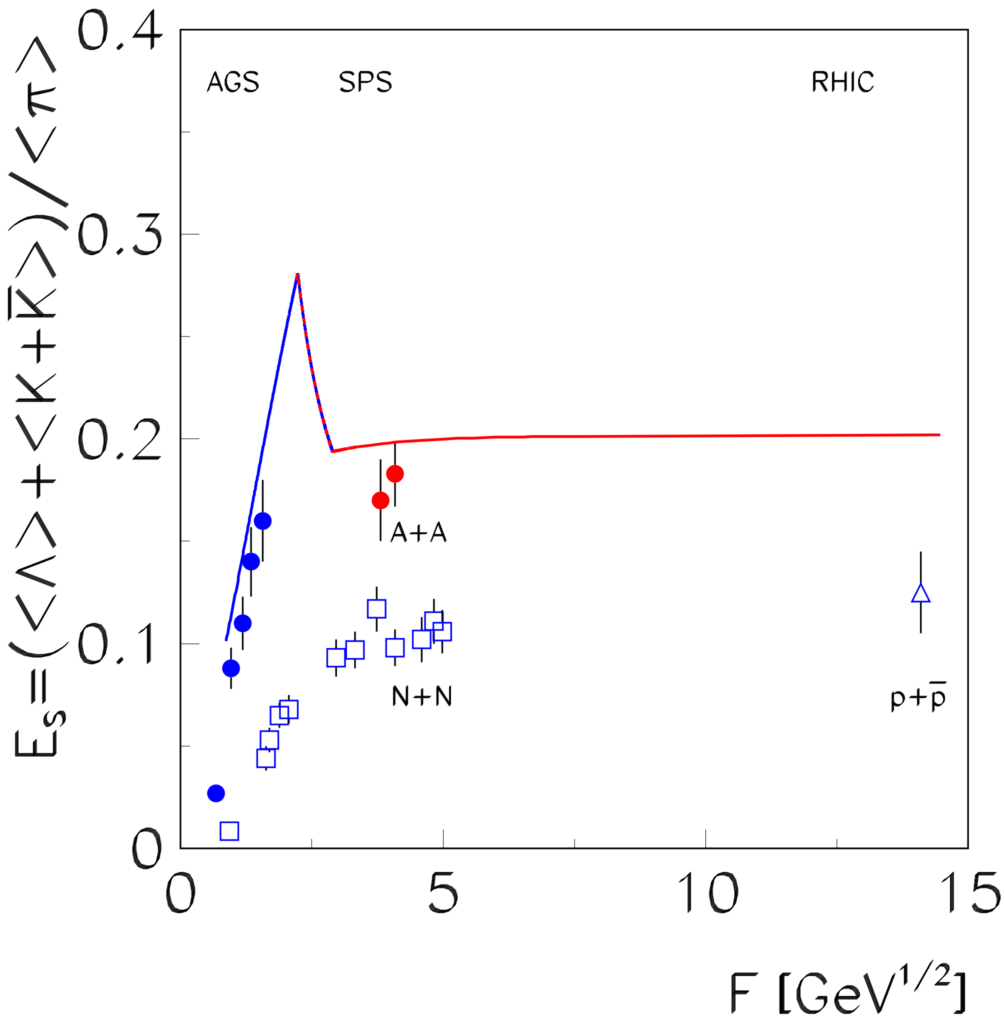

FIG. 1. Collision energy dependence of strangeness to pion ratio for central nucleus–nucleus [14] collisions (closed points), nucleon–nucleon [3] and $p + \bar{p}$ [15] interactions (open points). The predictions of the statistical model of the early stage for A+A collisions are indicted by solid line. Within the model one expects a non–monotonic dependence of the strangeness to pion ratio in the vicinity of the transition region and its saturation at the value characteristic for equilibrium QGP at high energies.